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AFWL HULL CALCULATIONS OF SQUARE-WAVE SHOCKS ON A RAMP.(U)
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AFWL HULL CALCULATIONS OF SQUARE-WAVE SHOCKS ON A RAMP

July 1977

Final Report

Approved for public release; distribution unlimited

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

AFWL-TR-77-82

This final report was prepared by the Air Force Weapons Laboratory, Albuquerque, New Mexico, under Job Order 88091816. Mr Charles E Needham (DYM) was the Laboratory Project Officer-in-Charge.

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The Air Force Weapons Laboratory (AFWL) has been tasked to perform hydrodynamic calculations using the HULL code, to predict peak airblast overpressure loading on structures. The code uses an Eulerian rectangular mesh. Geometric shapes within the grid are approximated by rectangular islands, where an island is a zone within the mesh for which all four boundaries are reflective. Thus, a ramp would be modeled as a stairway of islands. To demonstrate the validity of this approximation, a calculation was made which compares favorably with experiments. (Con't)

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20. Abstract (Con't)

conducted by the Ballistics Research Laboratory. Two other calculations were run to examine the use of nonsquare zoning as a valid approach to structure modeling.

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SECTION I

INTRODUCTION

The Air Force Weapons Laboratory (AFWL) has been tasked to perform hydrodynamic calculations which predict peak airblast overpressure loading on structures. The HULL (a 2-D Eulerian hydrodynamics) code uses a rectangular mesh to perform calculations (ref 1). Nonrectangular structures are approximated in the mesh by rectangular islands. An island is a zone for which all four boundaries are reflective. Thus, a ramp is modeled as a stairway (figure 1). It was not immediately clear whether this approximation was a valid one. In particular, would the peak-pressure and asymptotic (steady-state) values be correct?

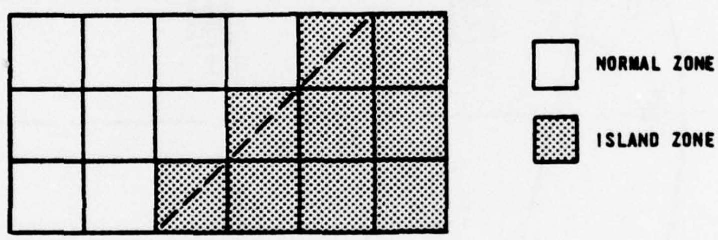

Figure 1. 45° Ramp Model

To test this hypothesis, the AFWL ran calculations which duplicated experiments conducted by the Ballistics Research Laboratory (BRL) of Aberdeen, Maryland (ref 2). In one experiment, a square wave of air traveling to the right at 90 psi was incident on air at an ambient level of 3.3 psi. The shock

1. Fry, M.A., et al., The HULL Hydrodynamics Computer Code, AFWL-TR-76-183, Air Force Weapons Laboratory, September, 1976.

2. Bertrand, B.P., Measurement of Pressure in Mach Reflection of Strong Shock Waves in a Shock Tube, BRL-MR-2196, Ballistics Research Laboratory, June 1972.

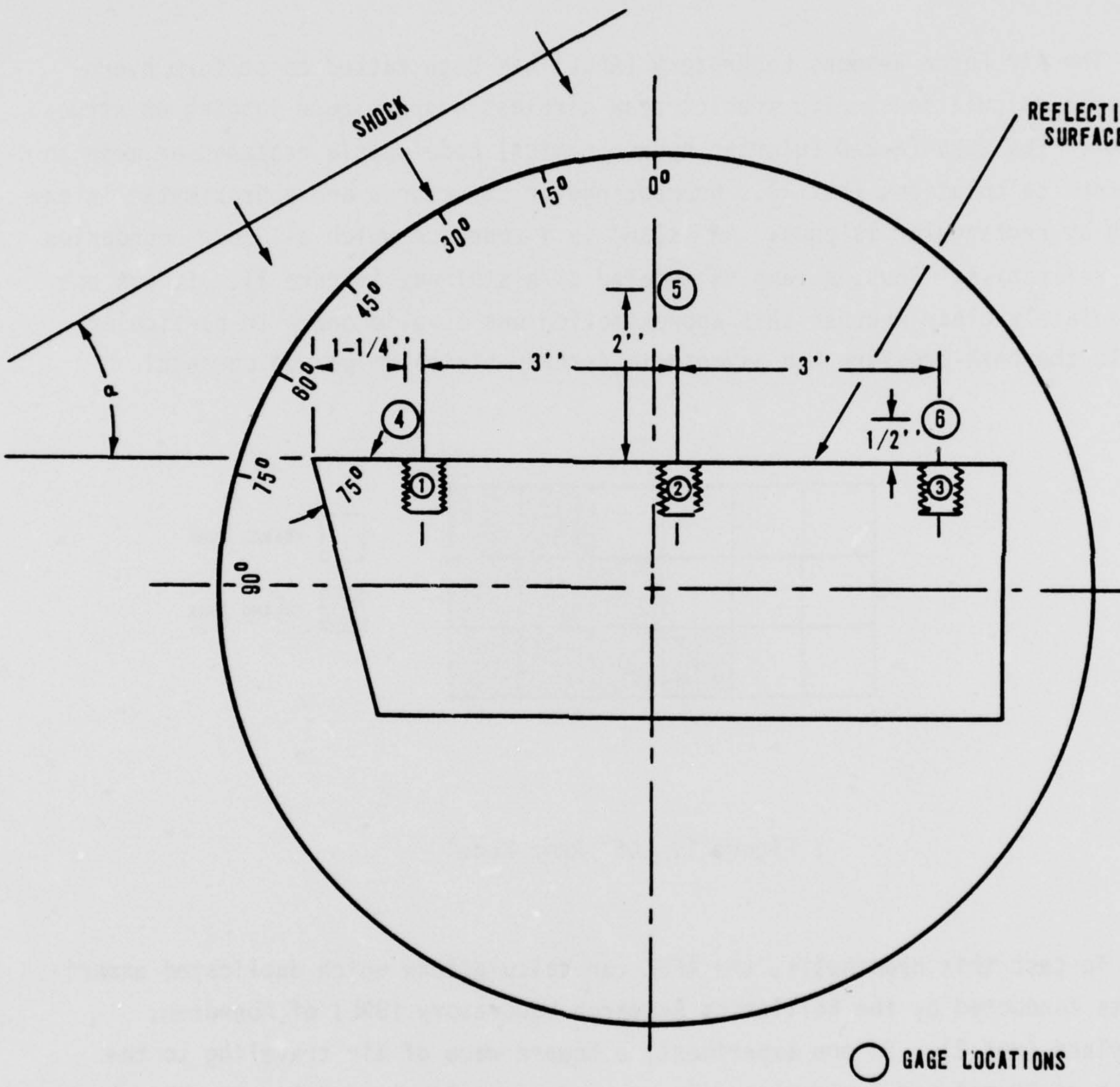

Figure 2. Station Locations for BRL Experiment

impinged on a ramp at an angle of 40° with the horizontal. There were station locations along the ramp and in the free air. Figure 2 is an illustration of the experimental setup.

For the HULL calculation, Rankine-Hugoniot relations specified the input conditions (see table 1). The zone sizes were dx = 0.3 cm, dy = 0.25173 cm; thus dy/dx = tan (40°). (The question of square-vs.-nonsquare zones is settled in the next section.) A real air equation of state was used, and there was no artificial viscosity included explicitly in the code. Figure 3 shows the station locations.

Table 1

INPUT MESH VALUES FOR THE CALCULATION

	Ambient	Incident
Pressure (dynes/cm^2)	2.275E5(3.3psi)	6.599E6(95.7psi)
Density (gm/cm^3)	2.783E-4	1.391E-3
Internal Energy (ergs/gm)	2.044E9	1.186E10
Horizontal Velocity (cm/sec)	0.	1.353E5

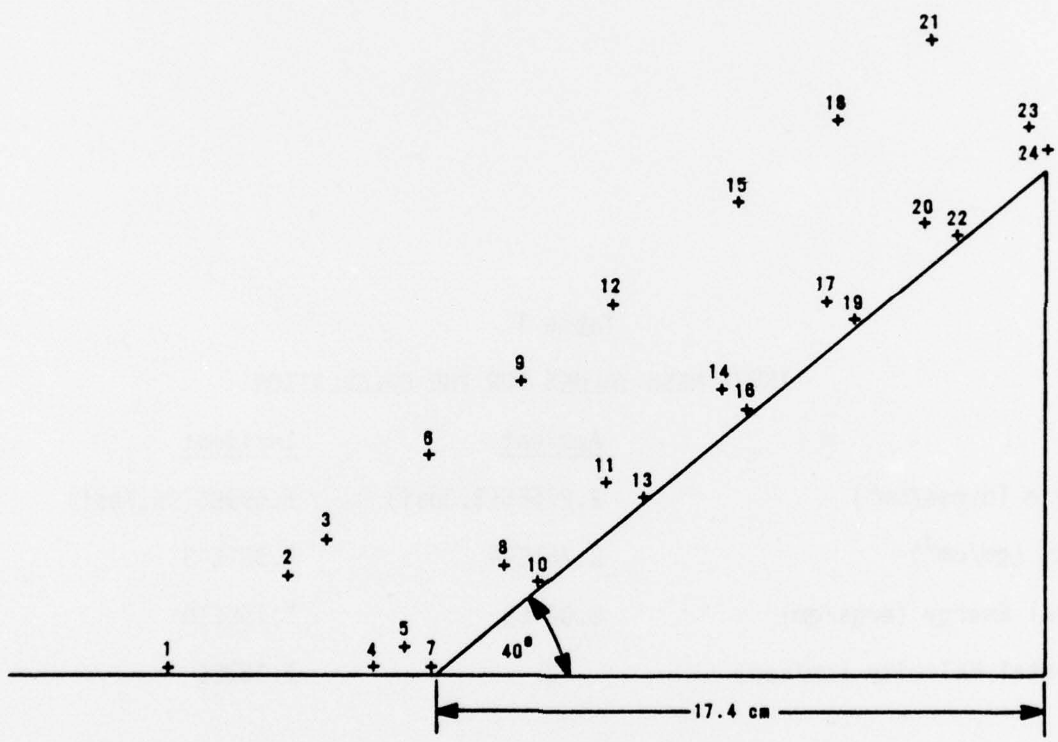

Figure 3. Calculation Station Locations

SECTION II

NUMERICAL AND EXPERIMENTAL COMPARISONS

Figure 4 shows a pressure-time history of stations 2, 3, 5 and 6 for the experiment. Notice that the peak-pressure is increasing as the shock travels up the ramp, i.e., station 2 has a peak-pressure of 478 psi and station 3 has a peak of 492 psi. The asymptotic pressure level at station 2 is approximately 310 psi; at station 3, 330 psi. Although the peak at station 6 (415 psi) is much smaller than at station 3, the steady-state value is about the same.

Figure 5 shows pressure-time histories for calculational stations 12, 16, and 22 which correspond most closely with experimental stations 5, 2 and 3, respectively, from figure 4. The first plateau at station 12 is the incident shock pressure level. For the BRL problem (station 5) it was 91 psi; for HULL (station 12), 6×10^6 dynes/cm^2 = 87 psi. Stations 2 and 3 in the BRL experiment have initial plateaus before reaching their peaks. This does not show up in the histories for stations 16 and 22 in the HULL calculations because of the smoothing of the shocks due to implicit internal viscosity. Figure 5d is a pressure contour along the ramp at 130 μs. For a 40° ramp, a pressure ratio of 29:1 is in the region of Mach reflection. Although the contour for this time shows regular reflection, the first contour above the ramp indicates the beginning of a merging of the incident shock and the reflected shock. If the ramp were longer, the shock would form a Mach stem.

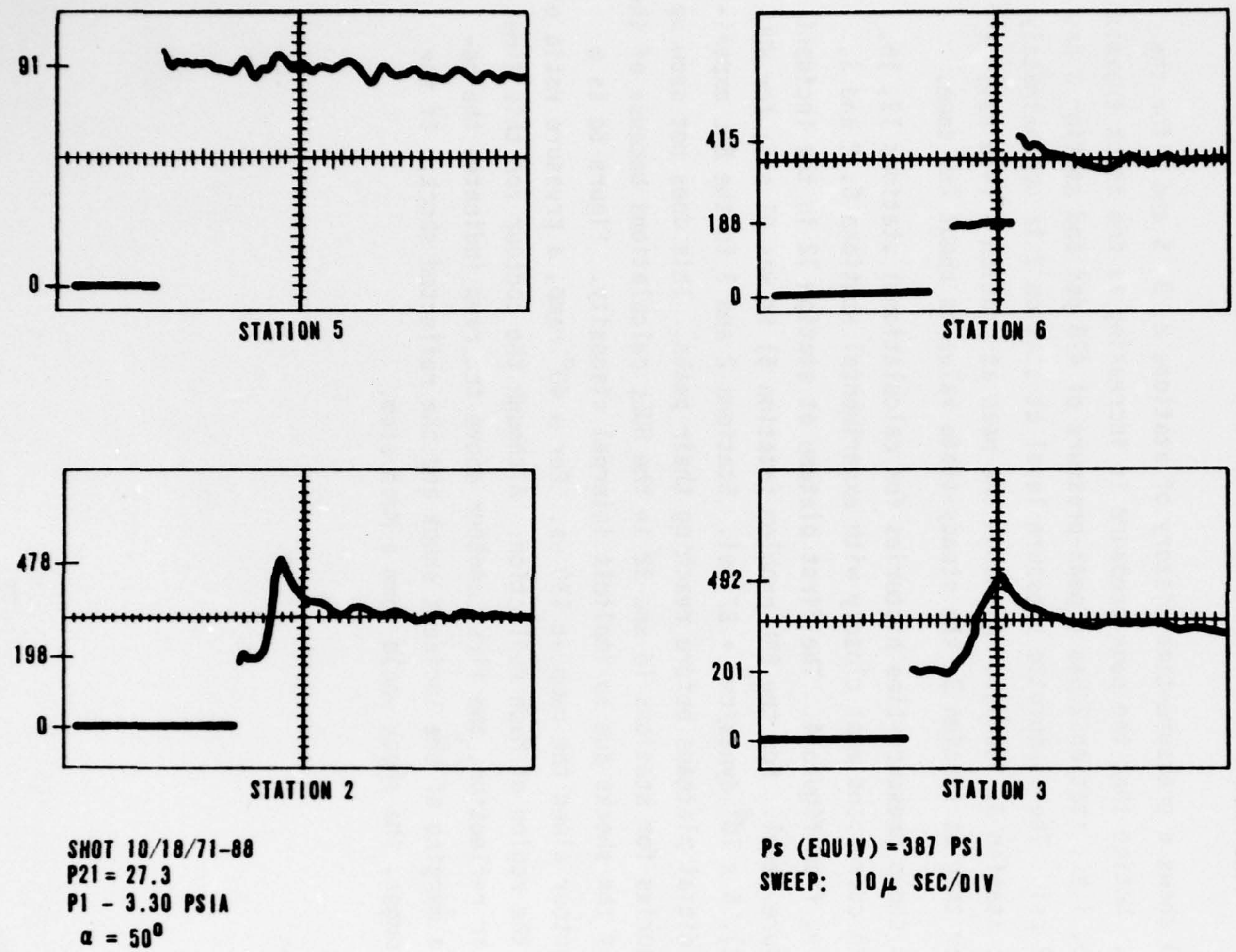

Figure 4. Pressure Records for BRL Experiment

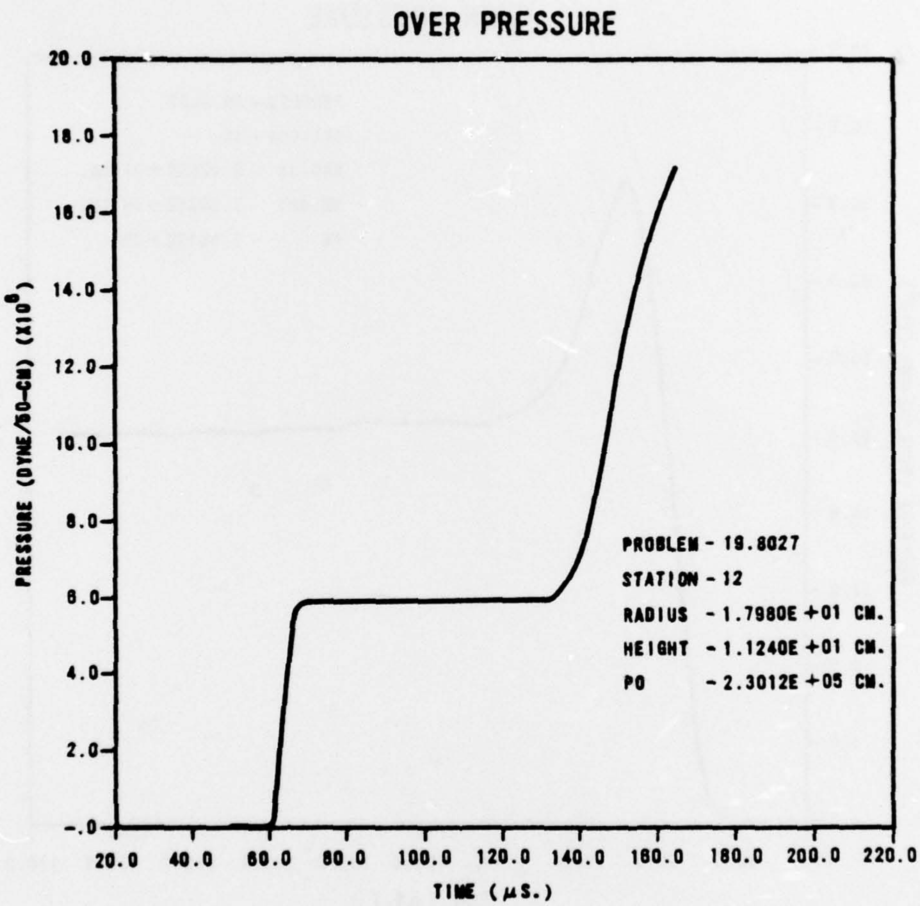

Figure 5a. AFWL-29 Square Wave-Ramp 40-Real Air-No Visc

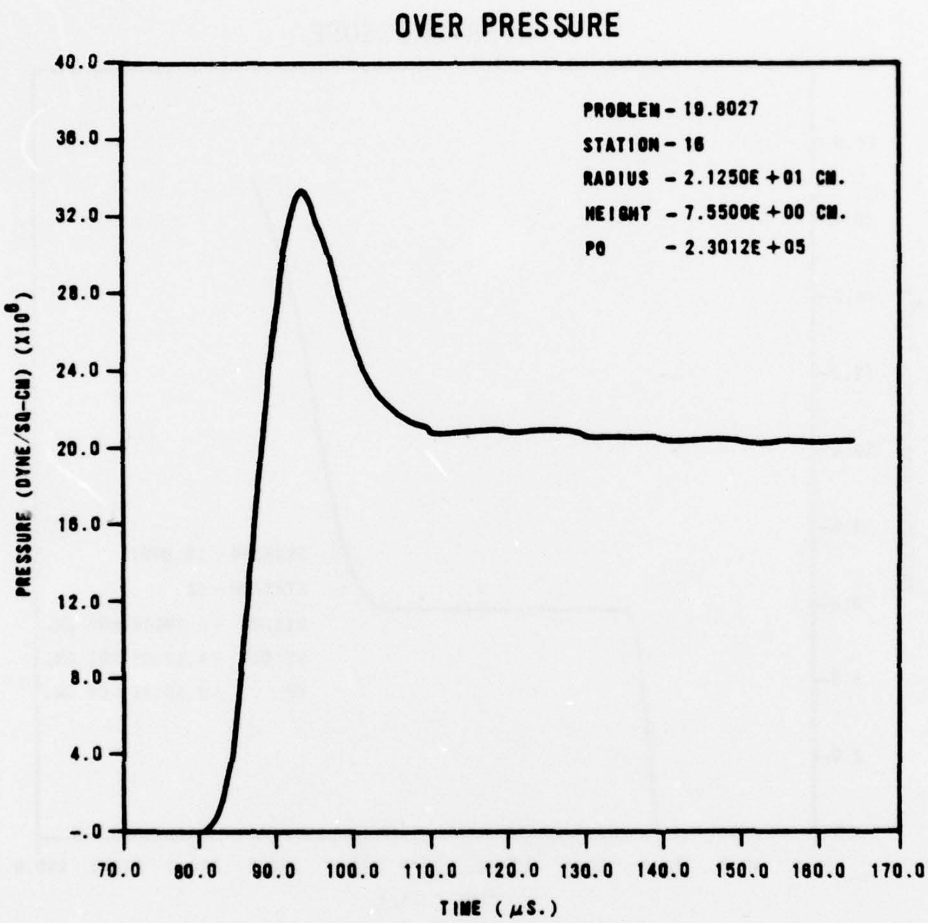

Figure 5b. AFWL-29 Square Wave-Ramp 40-Real Air-No Visc

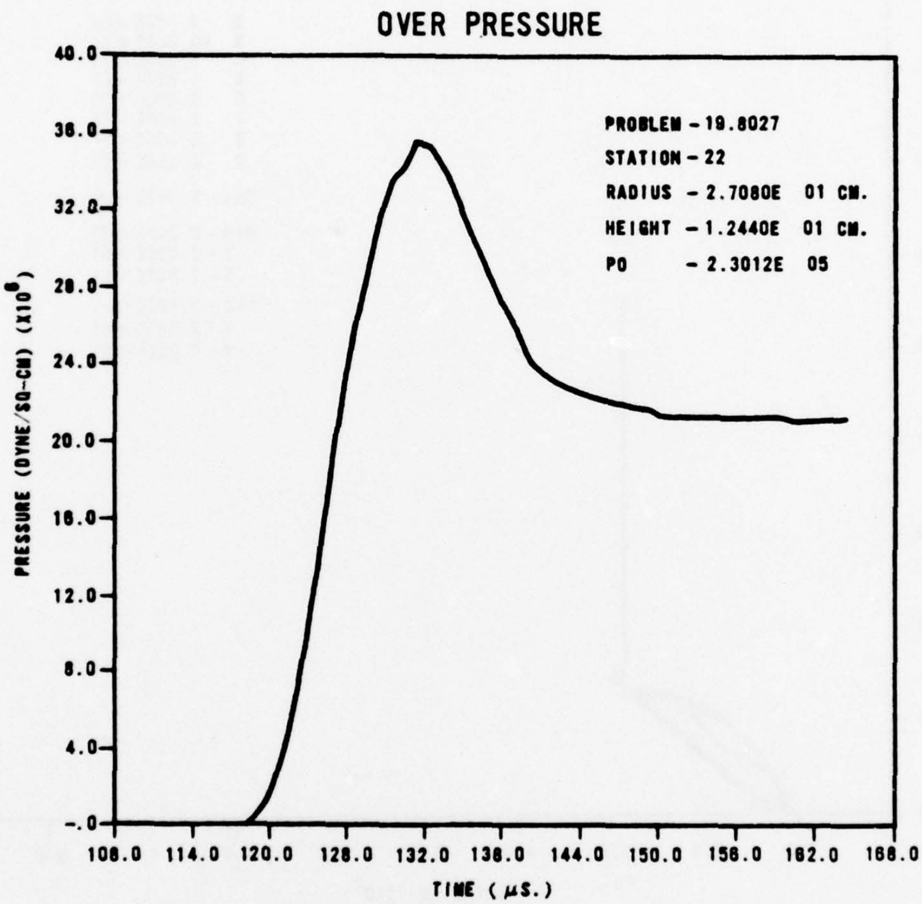

Figure 5c. AFWL-29 Square Wave-Ramp 40-Real Air-No Visc

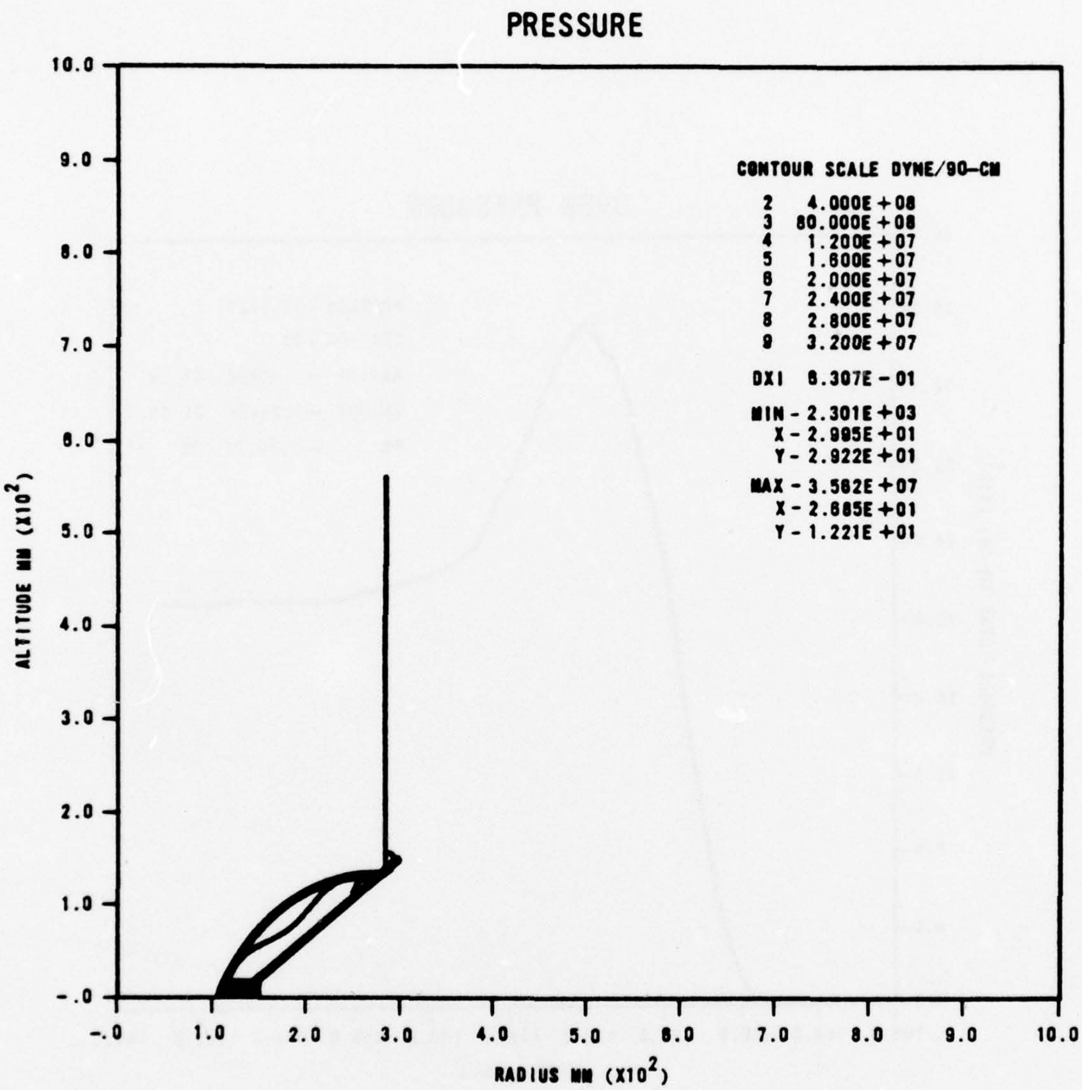

Figure 5d. AFWL-29 Square Wave-Ramp 40-Real Air-No Visc
Time 130.000 μs Cycle 121 Problem 19.8027

Table 2

COMPARISON BETWEEN HULL CALCULATIONS AND BRL EXPERIMENT

Station		Pressure (psi)	
BRL	HULL	BRL	HULL
5	12	91	87
2	16 (peak)	478	480
2	16 (steady-state)	310	310
3	22 (peak)	492	510
3	22 (steady-state)	350	310

Note the excellent agreement for stations 2 and 16. The agreement for stations 3 and 22 is reasonable.

SECTION III

SQUARE VS. NONSQUARE ZONES

When running hydrodynamic calculations, square zones are more efficient than nonsquare zones because the signal may cover a greater relative area per zone per time step. As was mentioned in the introduction, however, the HULL code models a ramp using rectangular islands. For a 10° ramp using rectangular islands. For a 10° ramp, the island locations for a grid with square zones would look something like figure 6,

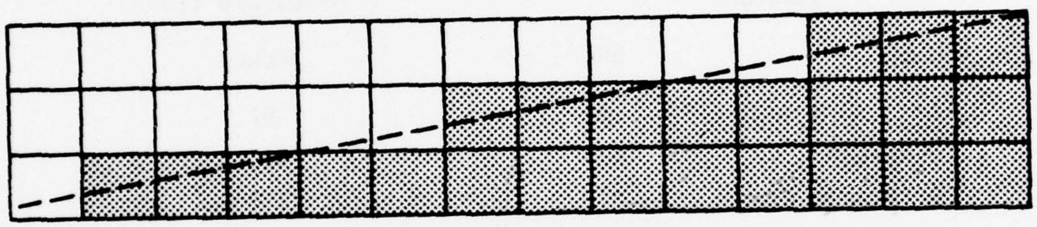

Figure 6. 10° Ramp Approximation - Square Zones

While for the island locations for a nonsquare zone grid where the ratio $dy/dx = \tan 10^{\circ}$, the island locations would look like figure 7.

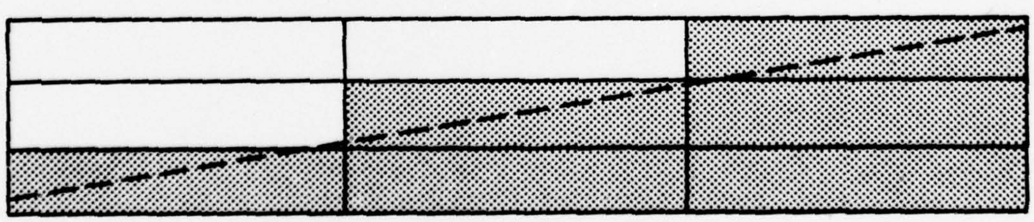

Figure 7. 10° Ramp Approximation - Nonsquare Zones

To test the impact of each zoning, two calculations were run. For each run, a 50-psi square wave was incident on a 10° ramp in a sea-level ambient atmosphere. The dx zone size was 0.3 cm and the equation of state was real air. An artifi-

cial viscosity function was used in both runs (ref. 3). The first calculation (19.8026) used a 0.3-cm dy zone size; the second (19.8029), a dy of 0.00529 cm.

Figure 8 gives a time history of the pressure at a station on the ramp approximately 6 cm from the base for each problem. Note the overshoot in pressure for the square zone problem. (The slightly different asymptotic values are due to the small difference in distances along the ramp). The overshoot is approximately 86 percent and would be totally unacceptable for problems where peak-loading is an important parameter. The reason for this overshoot can be seen from figures 9 and 10 where the horizontal and vertical velocities vs. time histories at the same station are shown. The square-zone problem does not have enough vertical relief. The vertical velocity begins 9 μs after the shock hits, whereas in the nonsquare zone problem, the time lag between the onset of the vertical and horizontal velocities is less than 2 μs. During this time the pressure builds until the vertical velocities become large enough to allow the mass flow out of the zone to equal the flow into the zone. Also, further analysis of these graphs indicates that the angle of the velocity vector in the square-zone problem reaches a maximum of 70° from the horizontal and then slowly moves to its asymptotic value of 45°. For the nonsquare zone problem, the velocity vector quickly reached its asymptotic value of 10° and remained there. Obviously, 10° is a more realistic value for the velocity angle, since the flow should parallel the 10° surface.

Once the flow has reached steady-state conditions, figure 11 illustrates another justification for using nonsquare zones for ramp calculations. It is a picture of the velocity vectors at the bottom of the ramp for the square zone problem at 190 μs. For this problem, the flow along the ramp encounters four zones with no reflecting right boundary before a vertical reflecting boundary is reached. So the flow attempts to become more horizontal to conform itself to the structure it sees until it reaches the reflecting zone. Then conservation of mass and momentum require that the velocity vector at the corner zone be somewhere in the neighborhood of 45° ($= \tan^{-1}(dy/dx)$). For the nonsquare zone problem, all velocity vectors at the corner zones were within 10% of 10°.

3. Lunn, P.W., et al., Development of an Artificial Viscosity Function, to be published.

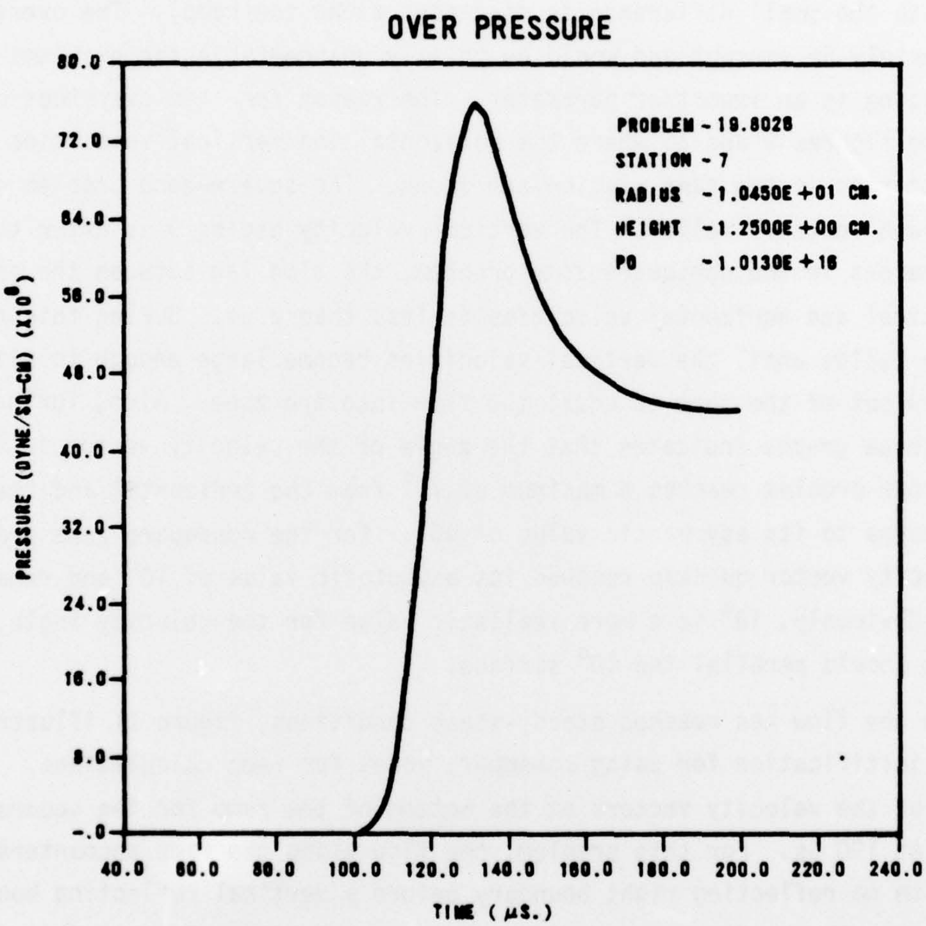

Figure 8a. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Square Zones

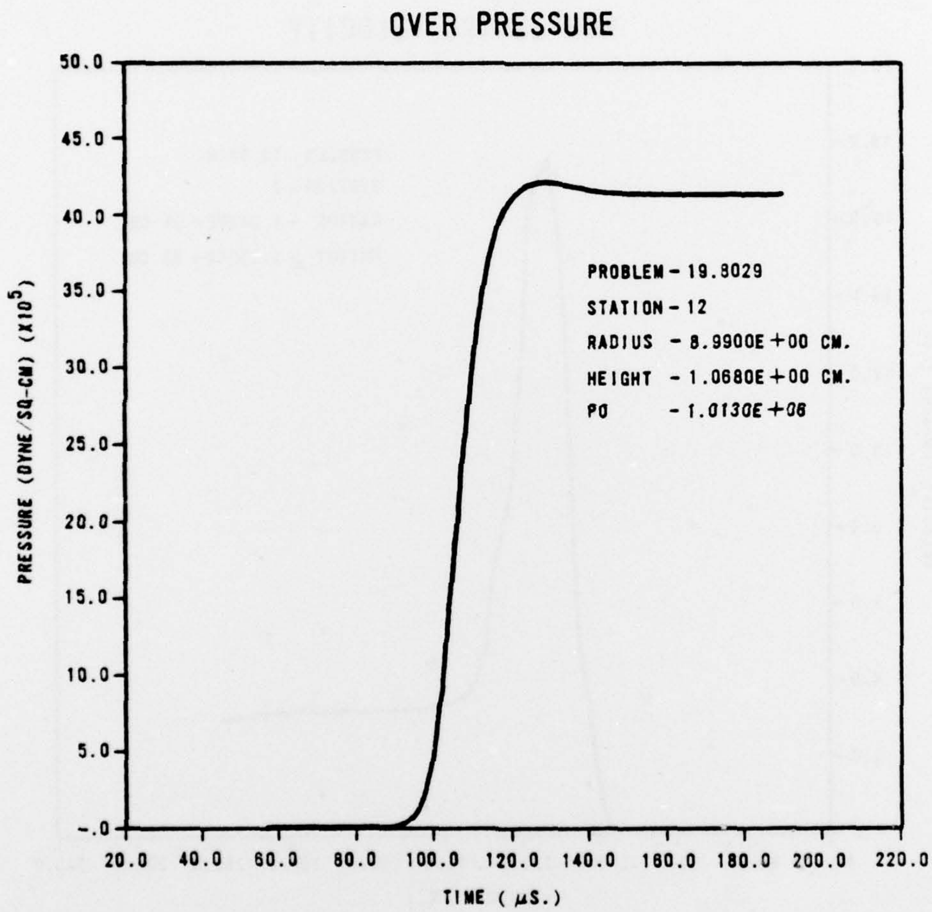

Figure 8b. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Nonsquare Zones.

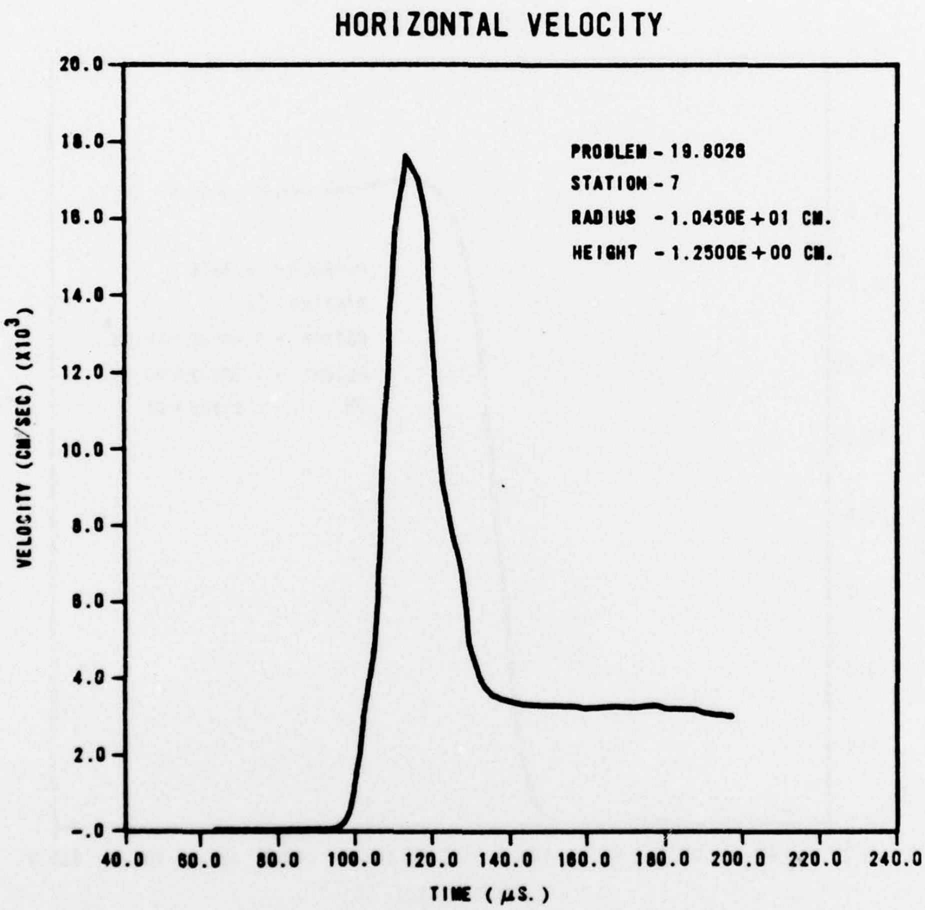

Figure 9a. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Square Zones

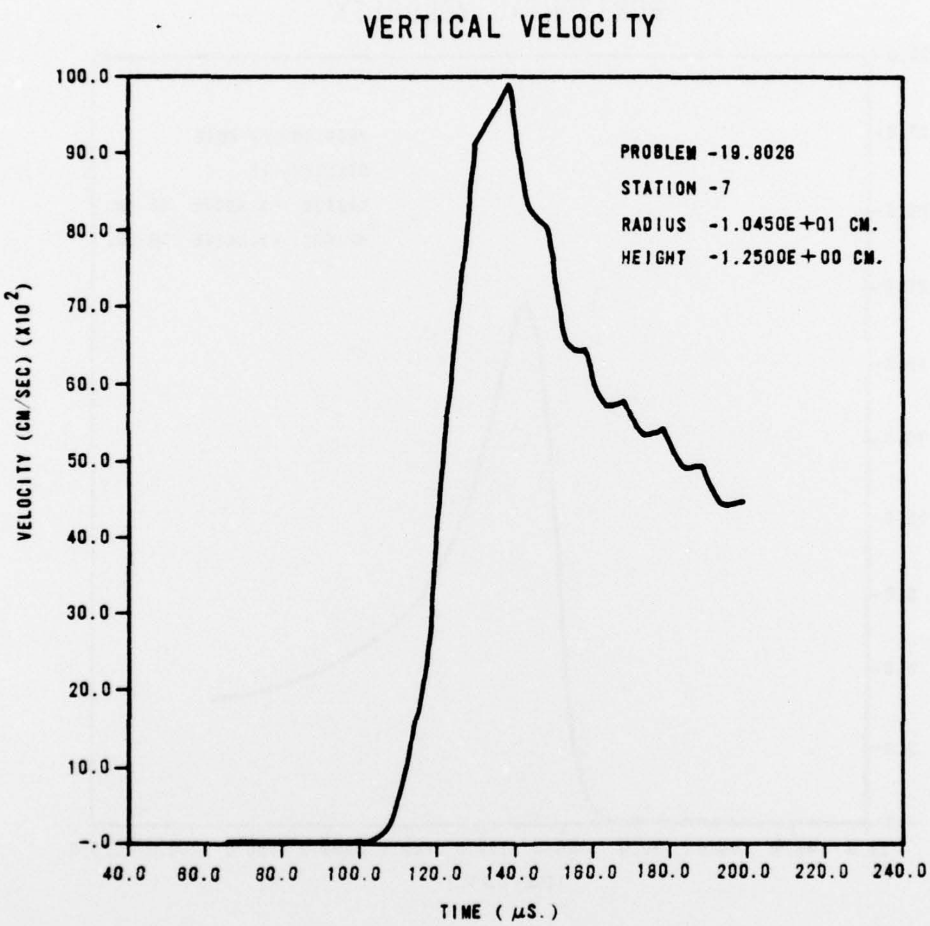

Figure 9b. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Square Zones

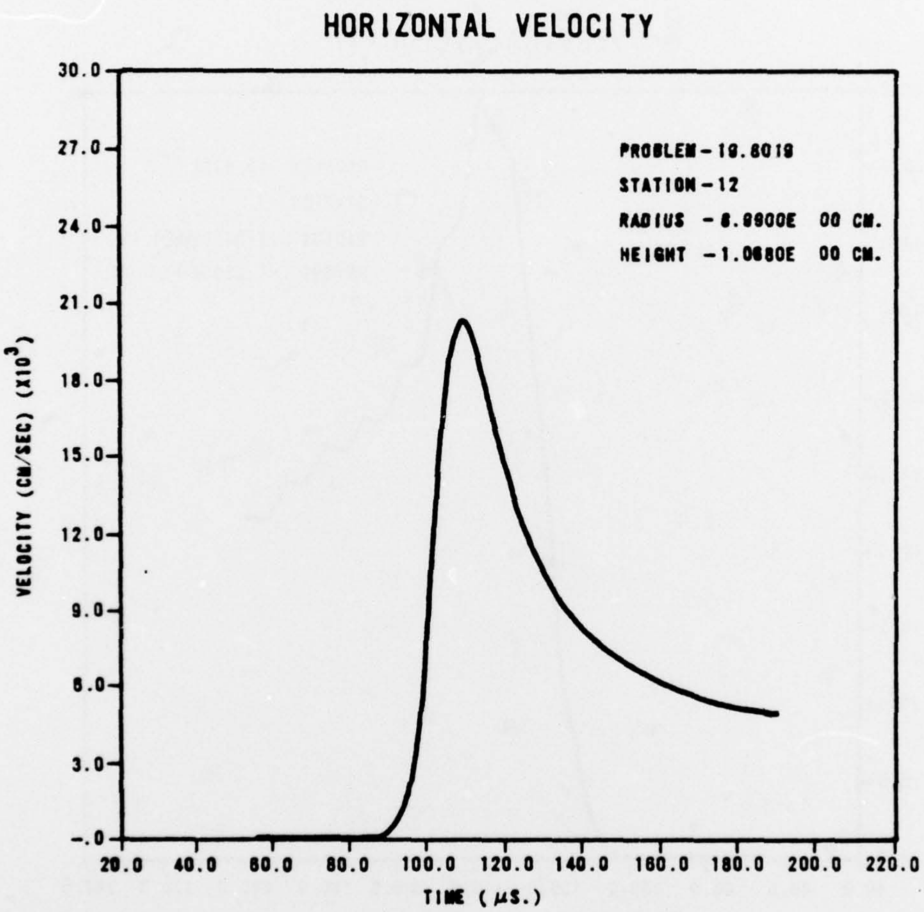

Figure 10a. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Nonsquare Zones

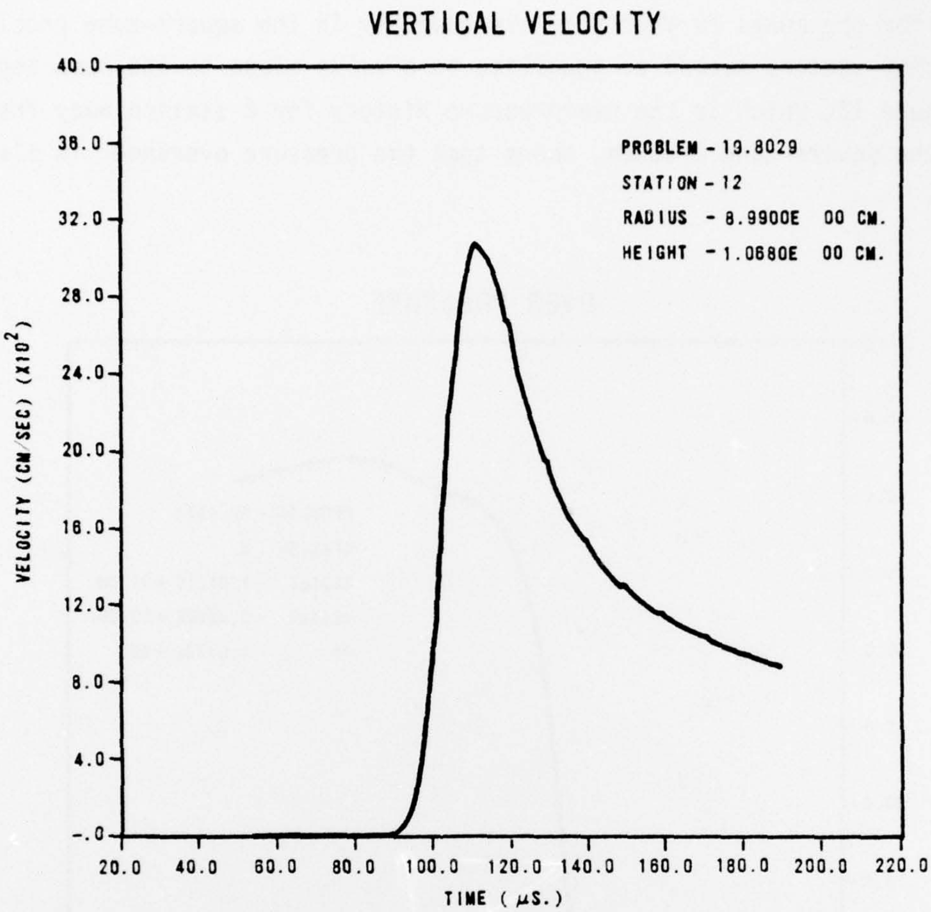

Figure 10b. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Nonsquare Zones

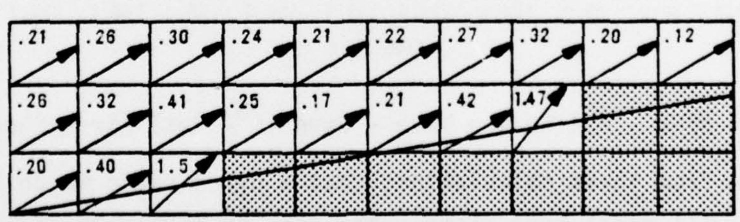

Figure 11. Veclocity Vector Angles for Square Zoning

However, for the zones further from the boundary in the square-zone problem, the velocity vectors seemed to stabilize to a value close to the ramp angle of 10°. Figure 12, which is the overpressure history for a station away from the ramp in the square-zone problem, shows that the pressure overshoot is also lessened.

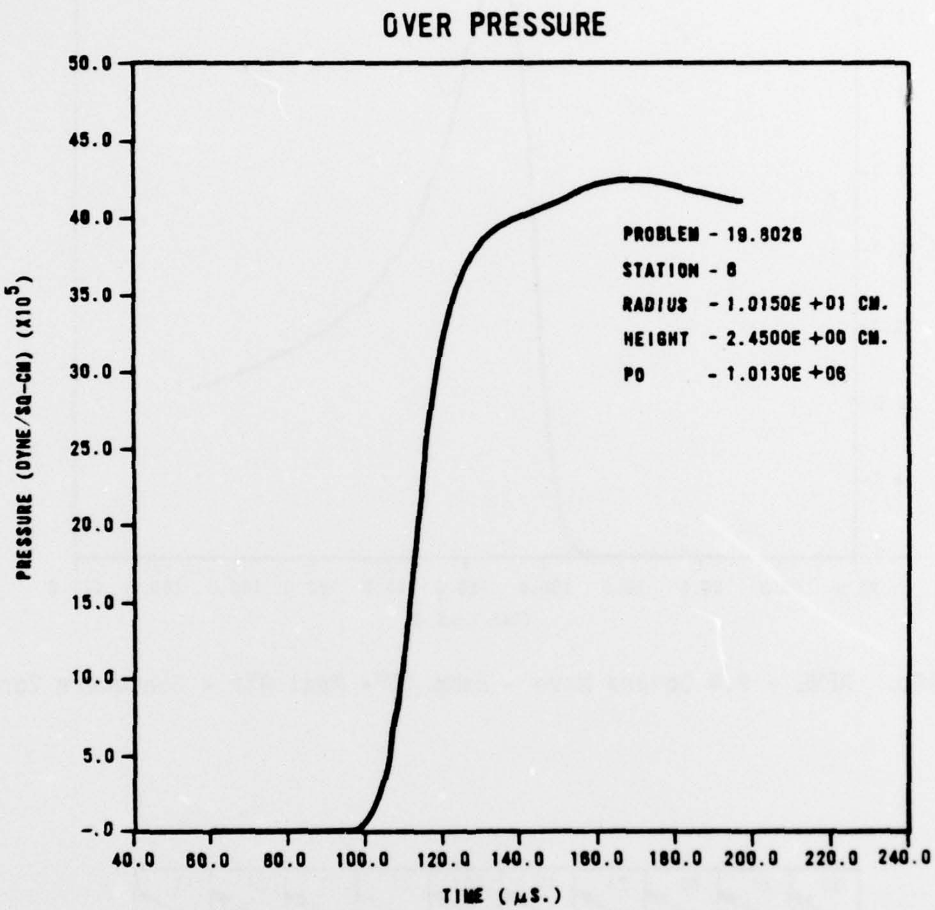

Figure 12. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Square Zones

We conclude from these calculations that a dy/dx ratio which approximates the ramp angle will model more closely the peak overpressure and other flow parameters close to the ramp than calculations using square zones.

Figures 13 and 14 show pressure contours for each calculation at 190 μs. The similarity of both of the curved bow shocks indicates that the inaccuracies close to the ramp induced by the square zoning are averaged so that gross motions remain nearly identical. Note in figure 13 the well developed Mach stem

as the shock travels up the ramp. For the BRL experiment, the reflection factor was 1.14 for the 10° ramp at 3.4 atmospheres overpressure. For the nonsquare-zone problem the reflection factor was 1.2.

Because square wave boundary conditions are used in these calculations, all parameters except time are independent of zone size. Thus reducing or increasing zone size does not change the value of peak pressures or velocity patterns. The geometric ratio alone determines the behavior of the flow variables for simple ramp structures.

Although a zone ratio (dy/dx) of $\tan^{-1} \theta$ will yield the most accurate results close to the ramp, other problem constraints may require a different zoning, e.g., a structure with more than one ramp at different angles. As was seen in the square-zone problem, further from the ramp the differences in zone size become less significant. Therefore, calculations with zone ratios which do not conform exactly to the ramp angle will still yield valid results if values right on the ramp are not considered. In addition, the peak overshoot for the overpressure will vary directly with the deviation of the zone ratio from the ramp angle. For small deviations the overshoot will be small.

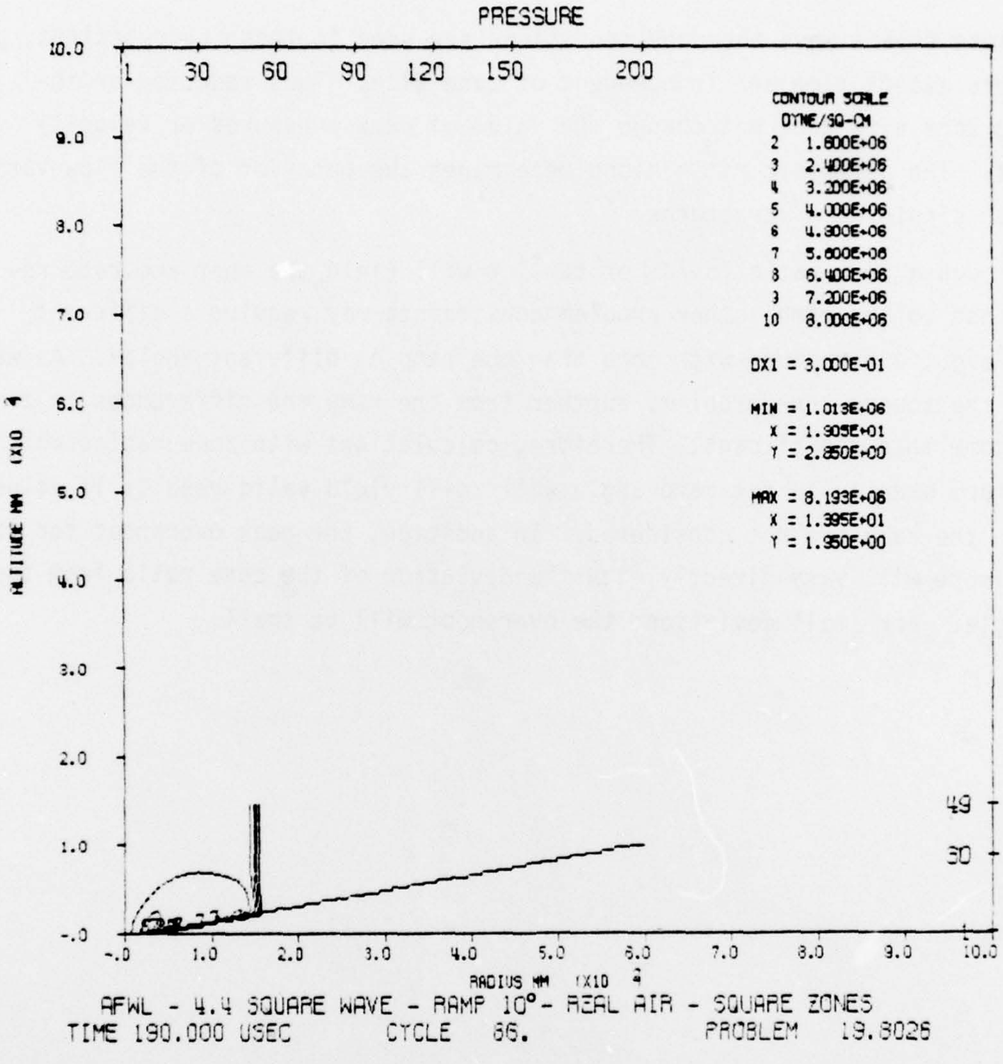

Figure 13. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Square Zones

Time 190.000 μs Cycle 86 Problem 19.8026

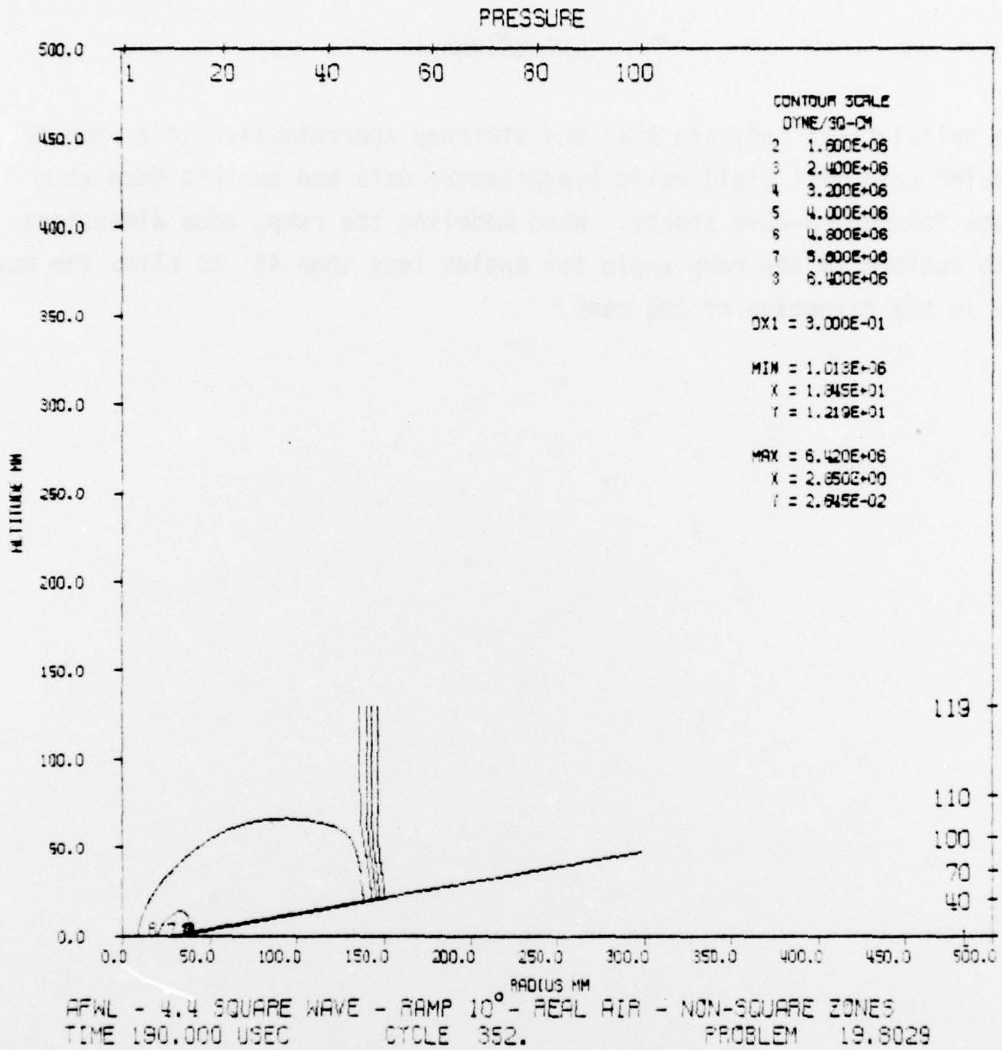

Figure 14. AFWL - 4.4 Square Wave - Ramp 10°- Real Air - Nonsquare Zones
Time 190.000 μs Cycle 352 Problem 19.8029

SECTION IV

CONCLUSIONS

The calculations indicate that the stairway approximation to a ramp for a rectangular grid will yield valid overpressure data and exhibit Mach stem phenomena for square-wave shocks. When modeling the ramp, zone dimensions ought to conform to the ramp angle for angles less than 45° to allow the material to flow in the direction of the ramp.

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